CHAPTER 2
Economic Potential for U.S. Offshore Aquaculture: An Analytical Approach

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This chapter presents an analytical approach for thinking about the economic potential for offshore aquaculture in the U.S. We review basic economics of aquaculture and discuss major factors which might affect the costs, prices, profitability, and competitiveness of such an industry.

Introduction

Our purpose is not to analyze the economic viability of any of the numerous, potential types of domestic offshore fish farming. The costs, prices, and economic viability of offshore fish farms may vary widely depending on species, location, technology, scale, and regulations. Rather, this chapter suggests a way of thinking about the economic viability of U.S. offshore fish farming in a logical and systematic manner. The discussion focuses mainly on offshore finfish farming rather than offshore shellfish farming, although many of the considerations in assessing economic potential are similar for both types of offshore aquaculture.

Box 2.1. Definitions for Selected Terminology Used in this Chapter.

<u>Offshore aquaculture</u>. Aquaculture in exposed ocean waters. As used in this chapter, offshore aquaculture does not necessarily mean aquaculture in federal waters.

<u>Inshore aquaculture</u>. Marine aquaculture in inshore waters (all marine aquaculture other than offshore aquaculture).

<u>Type of offshore aquaculture</u>. Farming of a particular species using a particular kind of technology.

<u>Fish farm</u>. An aquaculture operation (including both finfish and shellfish).

<u>Economic viability</u>. Whether or not a particular type of fish farming is likely to be profitable.

<u>Economic potential</u>. The scale at which a particular type of fish farming is likely to be economically viable, as measured (for example) in aggregate annual production.

We begin by discussing <u>three major challenges</u> in assessing the economic potential for U.S. offshore aquaculture. These are: 1) the limited experience to date with offshore aquaculture and the likelihood of continued change in key factors affecting economic potential, including technology, feed costs, and markets; 2) the diversity of potential types of offshore aquaculture; and, 3) the importance of the regulatory regime in affecting economic potential.

We next present a theoretical framework for thinking about the potential economic viability and economic potential of U.S. offshore aquaculture, using elementary <u>supply and demand analysis</u>. The main purpose of this discussion is to show that the economic viability of U.S. offshore fish farms depends on both supply and demand conditions both for U.S. offshore fish farms and for all other competing sources of supply. What matters is not whether competitors can produce fish at a lower cost, but whether they can produce enough fish at a lower cost to keep prices below levels at which U.S. offshore farming is profitable. The economic viability of U.S. offshore fish farming may change over time, in response to changes in the costs of conducting business, changes in competitors' costs, or changes in demand.

Next discussed are the basic economics of aquaculture: the major factors affecting fish farming costs and prices. We discuss four broad types of costs: facilities cost, feed cost, juveniles cost, and other operating costs, as well as the major factors that affect these costs.

We next consider the potential competitiveness of U.S. offshore fish farms: reasons for which their costs and prices might be higher or lower than those of competitors supplying the same markets. We first discuss the competitiveness of offshore farming relative to inshore faming, and then the competitiveness of United States offshore farming relative to offshore farming in other countries.

We then briefly discuss how economic modeling may be used to examine the economic viability of a fish farm. For purposes of illustration, we present a simple economic model of a hypothetical offshore fish farm raising a hypothetical fish species.

We conclude by considering the limits of economic studies for assessing potential long-term economic viability of industries with rapidly evolving markets and technology. It is suggested that the ultimate test of the economic viability of U.S. offshore aquaculture is the market. Without an enabling regulatory framework, such a test cannot happen and U.S. offshore aquaculture will not develop.

Finally, general observations are made about the economic potential for U.S. offshore aquaculture.

Challenges in Assessing the Economic Potential for U.S. Offshore Aquaculture

There are several fundamental challenges in assessing the economic potential for U.S. offshore aquaculture.

A first challenge is that the world offshore aquaculture industry is still in its infancy. In both the United States and other countries, there has been very limited experience with offshore aquaculture. As we discuss below, the economic potential for offshore aquaculture is likely to grow over time, for reasons including growing world demand for fish; growing demand for land, fresh water, and inshore waters for uses other than agriculture and aquaculture; and improvements in offshore aquaculture technologies. But we do not know how rapidly these changes may occur or what their cumulative effects might be. The farther we look into the future, the less certain we can be about the key factors which affect the economic potential for U.S. offshore aquaculture: what aquaculture technologies may evolve, what the resulting cost structures may be for onshore and offshore aquaculture, what prices of fish and other competing proteins will be, and how costs and prices for U.S. offshore fish farms may vary from those of competing nations.

A second challenge is that potential U. S. offshore aquaculture is very diverse. The United States has a very large exclusive economic zone with waters ranging from arctic to tropical. There are many different species which could be farmed in the U.S. EEZ, using many different types of technologies. Thus, there is not a single answer about the economic potential for U.S. offshore aquaculture. Rather, there are many answers for different regions, species, and technologies.

A third challenge is that the economic potential for U.S. offshore aquaculture depends critically on how it is regulated. How offshore aquaculture is regulated will directly affect where it may be developed, the species which may be farmed, the scale of projects which may be developed, the technologies which may be used, and costs such as environmental monitoring and taxes. How offshore aquaculture is regulated will also directly affect how long it takes for projects to be permitted and developed and the costs and risks associated with regulatory uncertainty and legal challenges. Thus, part of the answer to the question "what kind of offshore aquaculture could we have?" depends upon the answer to the question, "what kind of offshore aquaculture do we want?"

For all of these reasons, this chapter offers no definitive conclusions about the economic potential for specific types of U.S. offshore aquaculture. Rather, it frames a way of looking at the issues and suggests some tentative and general conclusions.

Economic Potential for U.S. Offshore Aquaculture: Insights from Supply and Demand Analysis

Supply and demand analysis provides a useful starting point for thinking about factors affecting the economic potential for U.S. offshore aquaculture. Here, we use supply and demand analysis to examine how potential competition from U.S. inshore farms[1], foreign farms, and wild fisheries might affect the economic potential for U.S. offshore farms.

For the purposes of this discussion, all of the supply and demand curves are given for fish of the same species.[2] For different real-world species, the supply and demand curves would have different shapes—with different implications for economic potential.

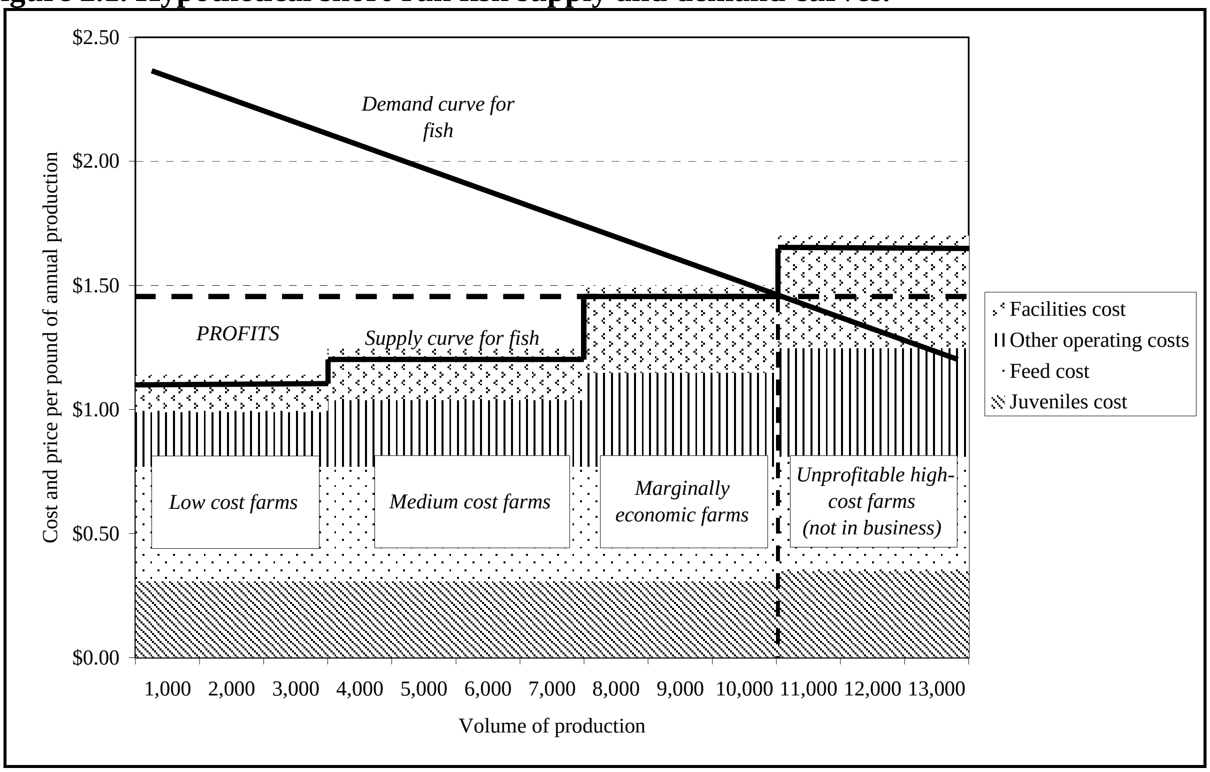
As we discuss in greater detail later in this chapter, each existing or potential farming operation for a particular species has a cost of production per pound. This cost may be expressed as the sum of costs per pound for facilities, feed, juveniles, and other operating costs.[3] These costs may vary between farms depending on their location, type of technology, scale of the operation, and the costs of various factor inputs (labor, energy, etc.). A farm is economically

[1] We use the term "inshore farms" to refer to marine aquaculture operations that are not "offshore"—in other words, farms in protected waters with limited exposure. For purposes of this discussion, we exaggerate the distinction between "inshore" and "offshore farming." In reality, there is a continuum between "inshore" and "offshore" farming, as farming occurs in waters of progressively greater depth, exposure, and distance from shore.
[2] Alternatively, they could be viewed as being for multiple species which are close market substitutes.
[3] By "facilities cost per pound" we refer to the cost per pound of multi-year investments in pens, vessels, and other facilities, expressed on an equivalent annual cost per-pound basis, and including a rate of return equal to the risk-adjusted opportunity cost of capital.

viable if and only if the price it receives per pound is greater than or equal to the total cost of production per pound (including the risk adjusted cost of capital).

As illustrated in Figure 2.1, we may plot the costs of all existing and potential fish farms for a particular species on a graph, with costs per pound on the vertical axis, and annual production on the horizontal axis arranged in ascending order of cost per pound. Plotted in this way, the total costs per pound form a supply curve for the species: the horizontal axis shows the volume of fish production that is economically viable at any given price per pound.

Figure 2.1. Hypothetical short-run fish supply and demand curves.



We may also plot a demand curve in the same figure, showing the volume of fish that is demanded at any given price. In the example shown in Figure 2.1, the demand curve and the supply curve determine the equilibrium price ($1.50/lb) and aggregate production (10,000 metric tons).

Note that in this example, low-cost farms and medium-cost farms are earning profits. The marginally economic farms are earning zero profits and are just able to stay in business. Unprofitable high-cost farms are not in business.

This simple figure illustrates a basic but important point in considering the economic potential for offshore aquaculture. It is possible for a fish farm to be economically viable even if other farms have lower costs, as long as the total supply from lower-cost farms remains limited. What matters for the economic viability of offshore aquaculture is not whether some competitors can produce fish at a lower cost, but whether they can produce enough fish at a lower cost to hold down the price below levels at which U.S. offshore aquaculture production is profitable.

We may use this supply and demand framework to discuss factors affecting the ability of U.S. offshore aquaculture to compete with three potentially lower-cost competitors: 1) domestic inshore aquaculture; 2) foreign aquaculture; and 3) wild fisheries.

Competitiveness of U.S. Offshore Aquaculture with U.S. Inshore Aquaculture

Considering first U.S. inshore aquaculture, for purposes of illustration we make two simple assumptions about the shape of the U.S. marine aquaculture supply curve:

- As aquaculture production moves offshore, from sites with relatively low exposure to sites of moderate and high exposure, costs of production increase.
- There are a limited number of potential farming sites with low exposure; there are more sites with moderate exposure; and there are a great number of sites with high exposure.

Given these assumptions, we might expect the supply curve for U.S. marine aquaculture to look something like that shown in Figure 2.2. Costs of production are relatively low for a limited number of inshore sites with low exposure to waves and wind. As farming expands to the limited number of sites with moderate exposure, costs of production increase. As farming expands to offshore areas with high exposure, costs increase further and the supply curve flattens out because of the very large offshore area potentially available for farming.[4]

Figure 2.2. Hypothetical U.S. marine aquaculture supply curve.

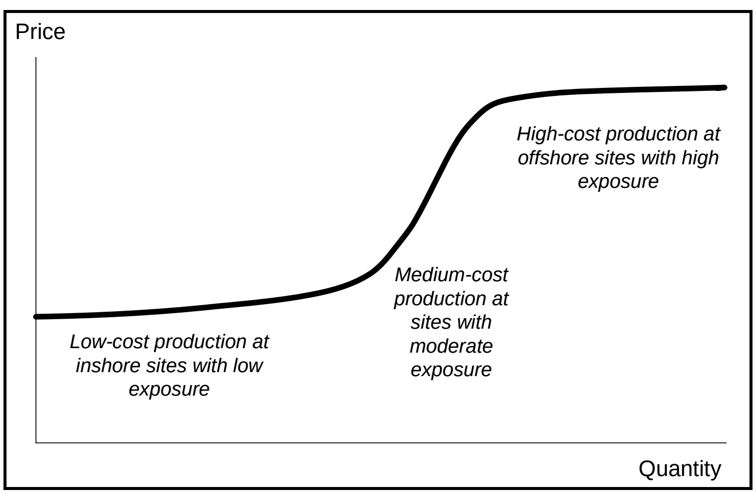


Figure 2.3 illustrates a domestic situation in which offshore aquaculture would *not* be economically viable because of competition from inshore aquaculture. The demand curve for fish intersects the supply curve at an equilibrium quantity, Q, which can be met by lower-cost

[4] It is not necessary to assume that the supply curve has the shape shown in the figure. The only essential assumptions for this discussion are that the supply curve is upward sloping, and that offshore farms have higher costs and become economically viable only at higher prices. It could be argued that the supply curve should not "flatten out" even as production reaches offshore sites with high exposure, because the costs of other inputs, such as feed and juveniles, would continue to increase as production increases.

inshore farms. The equilibrium price, P, is too low for offshore farms to be profitable. Thus, offshore farming will not be economically viable if lower-cost inshore farms can fully meet demand at prices below the cost of offshore farming.

Figure 2.3. Demand and supply conditions in which offshore farming is not economically viable because lower-cost inshore sites can meet demand.

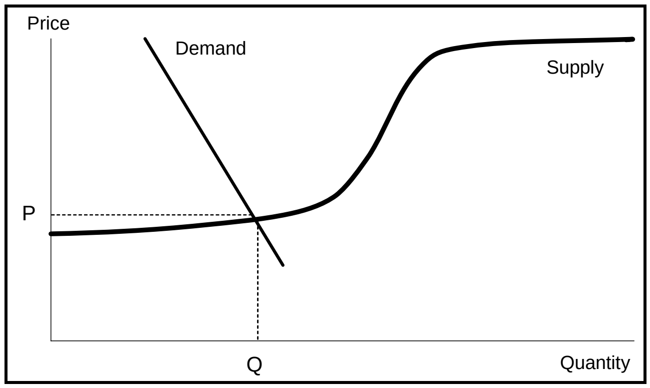


Figure 2.4 illustrates four ways in which demand or supply conditions could change from those in Figure 2.3 so that offshore aquaculture would become competitive with inshore aquaculture:

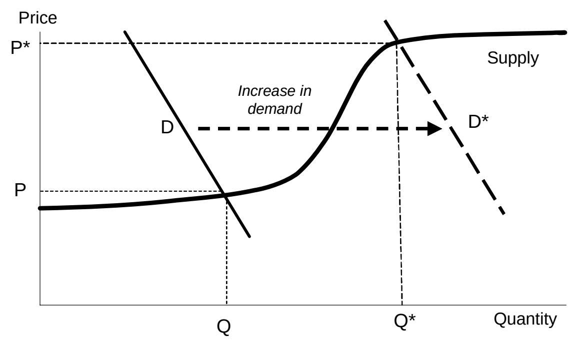
- Higher-cost offshore farms can compete with lower-cost inshore farms if demand exceeds the volume that can be produced from lower-cost, inshore sites (Figure 2.4A).
- Offshore farms can compete with inshore farms if costs for offshore farming decline sufficiently to become competitive with inshore farming (Figure 2.4B).
- Offshore farms can compete with inshore farms if the availability of inshore sites declines so that inshore farms are no longer able to meet demand (Figure 2.4C).
- Offshore farms can compete with inshore farms if the cost of inshore farms increases so that offshore farms are competitive with inshore farming (Figure 2.4D).

Note that two of the situations illustrated by Figure 2.4 have nothing to do with the relative costs of inshore and offshore fish farming. Even if inshore farming incurs lower costs, offshore farming can successfully compete with inshore farming if demand increases sufficiently or if the number of inshore sites declines sufficiently.

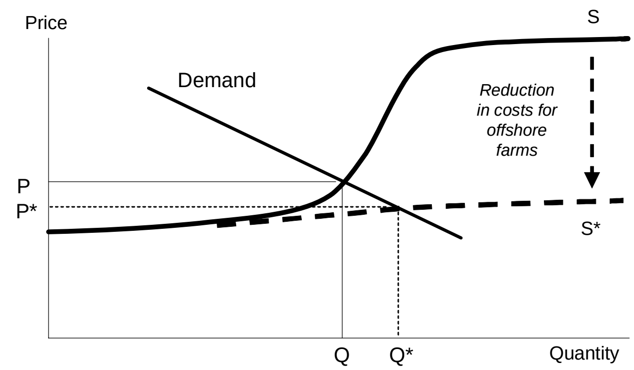
Some kinds of fish farming may impose externalities—additional costs to society not paid by farmers—such as wastes, navigational obstacles, or visual impacts. As discussed in other chapters of this report, some of these externalities may decline as aquaculture moves offshore. For example, an offshore farm may have less of a visual impact and may have less of an impact on water quality than an inshore farm.

Figure 2.4. How offshore aquaculture could become competitive with inshore aquaculture.

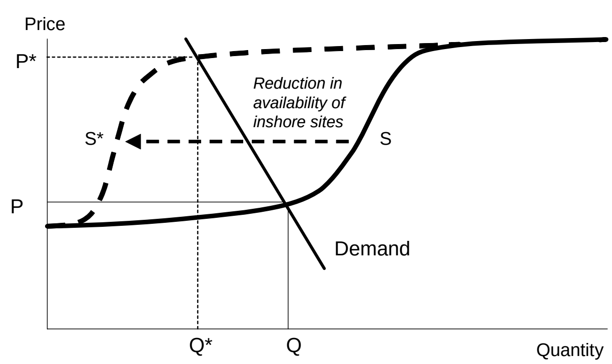
A. Demand increases. As demand increases, lower-cost inshore sites are fully utilized and farming expands to higher-cost offshore sites. The rise in price to P* makes offshore farming economically viable.



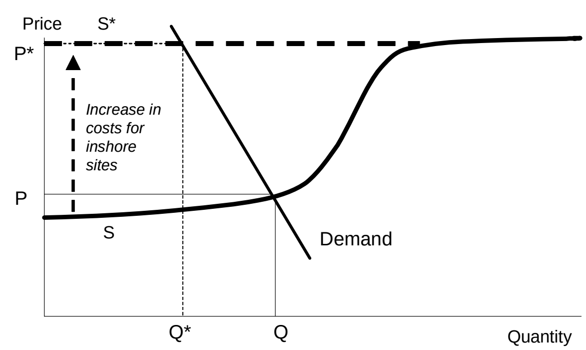
B. Technological change reduces offshore costs. Offshore farming becomes relatively less costly. Price declines and offshore production expands.



C. Supply of inshore sites declines. As demand for other uses of coastal areas increases, the supply of inshore sites becomes lower and farming moves to higher-cost offshore sites. The rise in price to P* makes offshore farming economically viable.



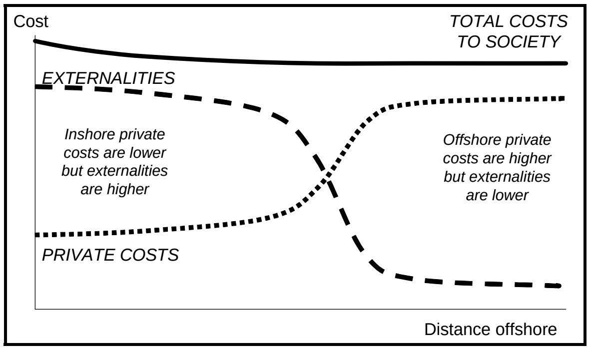
D. Regulations increase inshore costs. Regulators impose new costs on inshore farming to address externalities, making offshore farming relatively more competitive. The rise in price to P* makes offshore farming economically viable.



In theory, as illustrated in Figure 2.5, if externalities decline sufficiently as farms move offshore, then even if the private costs of offshore farming are higher than those of inshore farming, the total costs to society could be less. If this were the case, then increasing the costs of inshore farming to "internalize the externalities"—for example, through taxes—could make offshore farming economically viable. (This scenario was illustrated by Figure 2.4D)

Figure 2.5. Hypothetical fish farming private costs and externalities.

If externalities decline as farming moves offshore,
total costs to society could be lower for offshore farms.



Competitiveness of U.S. Offshore Aquaculture with Foreign Offshore Aquaculture

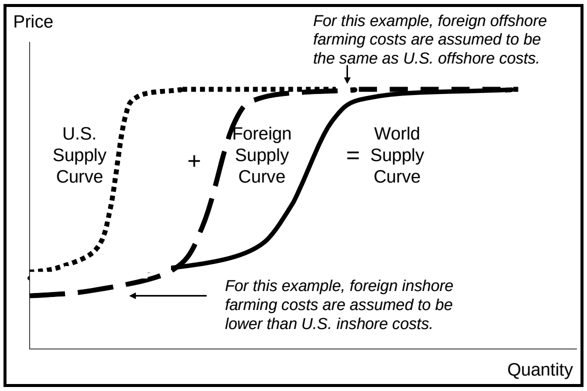
Considering next the competition from foreign aquaculture, we assume for purposes of discussion that for some kinds of foreign aquaculture—inshore, offshore, or both—costs are lower than those in the United States. Lower costs could result from a variety of factors, such as reduced labor costs, government subsidies, or less stringent environmental regulation or enforcement.

One potential situation is illustrated in Figure 2.6, in which we have assumed that foreign costs are lower than domestic costs for inshore aquaculture, but that the costs of foreign offshore aquaculture would be the same as those in the United States. We have drawn the supply curve for foreign aquaculture as similar in shape to that for U.S. aquaculture, but farther to the right, because for any given price, foreign producers are able to supply a greater volume than U.S. producers. The world supply curve—which shows the total volume supplied to world markets for any given world price—is the horizontal sum of the United States and foreign demand curves.

Figure 2.7 illustrates two situations in which U.S. offshore aquaculture would *not* be economically viable because of competition from foreign aquaculture. In Figure 2.7A, the demand curve for fish intersects the supply curve at an equilibrium quantity, Q, which can be met by lower-cost, foreign inshore farms. The equilibrium price, P, is too low for either U.S. or foreign offshore farms to be profitable.

In Figure 2.7B, foreign offshore farms exhibit lower costs than U.S. farms. Although demand is high enough for foreign offshore farms to be profitable, the world price is too low for U.S. offshore farms to be profitable (although it is high enough for U.S. farms on sites with moderate exposure to be profitable).

Figure 2.6. Hypothetical U.S., foreign, and world marine aquaculture supply curves.



U.S. offshore farms will not be competitive if they have to match prices for lower-cost foreign inshore or offshore farms, and those farms can satisfy world demand at prices less than the cost of U.S. offshore farms.

Figure 2.7. Situations in which U.S. offshore aquaculture would not be economically viable because of competition from foreign aquaculture.

A. Inshore sites can meet demand. There is sufficient production from low-cost foreign and U.S. inshore sites to meet world demand.

B. Foreign offshore costs are lower. Even though world demand exceeds that which can be supplied by inshore sites, foreign offshore production can meet world demand at prices at which U.S. offshore production is not profitable..

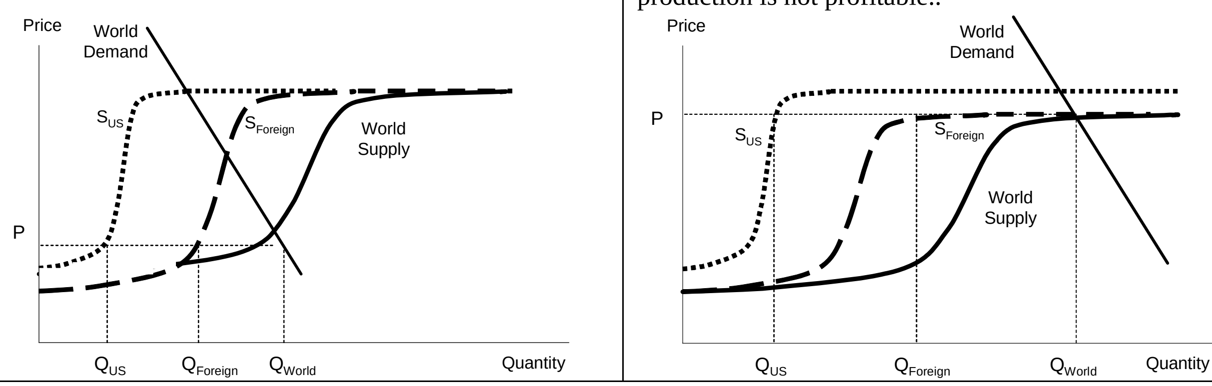
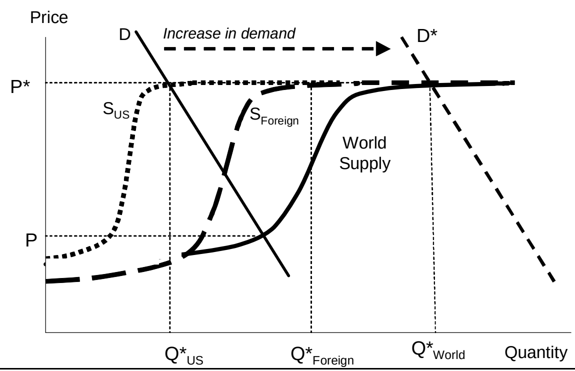


Figure 2.8 illustrates two ways in which demand or supply conditions could change so that U.S. offshore farming could become competitive with foreign farms.

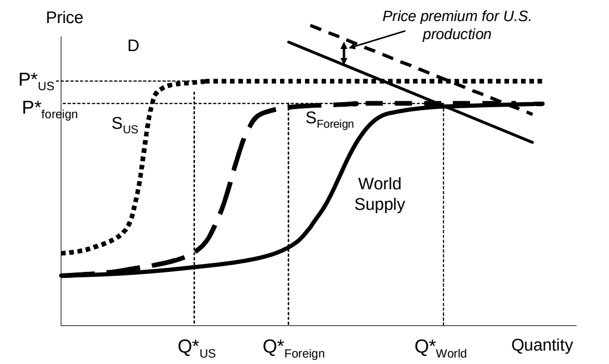
- U.S. offshore farms can compete with lower-cost foreign inshore farms if their costs are similar to foreign offshore costs, and if demand expands sufficiently so that lower-cost U.S. and foreign inshore sites are fully utilized, causing prices to increase to levels at which U.S. offshore farming is profitable (Figure 2.8A).
- U.S. offshore farms can compete with lower-cost foreign inshore or offshore farms if U.S. offshore farms are able to command a price premium over the world market price; for example, due to lower costs of transport to the U.S. market or perceived higher quality (Figure 2.8B).

Figure 2.8. How U.S. offshore aquaculture could become competitive with foreign aquaculture.

A. U.S. is competitive offshore. Even though the U.S. is not competitive in inshore aquaculture, it can match costs of foreign producers in offshore aquaculture.



B. U.S. offshore production enjoys a price-premium. Even if foreign offshore costs are lower, U.S. offshore farms may be competitive if they command a price premium over foreign production.



Competitiveness of U.S. Offshore Aquaculture with Wild Fisheries

Considering, finally, competition from wild fisheries, this could be modeled similarly to the way we have modeled competition between U.S. offshore aquaculture and foreign aquaculture. (To avoid repetition, these supply and demand curves have been omitted.) A key difference is that total supply from wild fisheries is limited by nature. Thus, the supply curve becomes steeper and, ultimately, vertical as production increases.

Following the same reasoning as discussed above, U.S. offshore farms cannot compete with wild fisheries if they have to match prices for lower-cost wild fisheries and if wild fisheries can satisfy world demand at prices below the costs of U.S. offshore farms. However, U.S. offshore farms can compete with wild fisheries if wild fisheries cannot fully satisfy world demand, allowing prices to rise to levels at which U.S. offshore farms are profitable—or if U.S. offshore farms can command a sufficient price premium over lower-cost, wild fisheries.

An Algebraic Restatement

We may make the same points about the potential competitiveness of higher-cost offshore aquaculture in a different way using simple algebra and the following definitions:

Offshore cost	=	Cost per pound for offshore farms
Competitor cost	=	Cost per pound for competitors of offshore farms
Offshore price	=	Price paid for fish produced by offshore farms
Competitor price	=	Price paid for fish produced by competitors of offshore farms
Competitor profitability	=	Competitor price – Competitor cost
Offshore cost premium	=	Offshore cost – Competitor cost
Offshore price premium	=	Offshore price – Competitor price

Offshore farming will be viable if:
Offshore cost < Offshore price

Subtracting "competitor cost" from both sides of this equation, and subtracting and adding "competitor price" on the right-hand side of the equation, we may rewrite this condition as:

(Offshore cost – Competitor cost) < (Offshore price – Competitor price) + (Competitor price – Competitor cost)

Simplifying, we may restate the condition for higher-cost offshore farming to be profitable as:

Offshore cost premium < Offshore price premium + Competitor profitability

Thus, higher-cost offshore farming can be viable as long as the difference in costs is less than the sum of any offshore price premium (if there is one) and lower-cost competitors' profits. Put differently, if lower-cost competitors are earning sufficiently high profits, higher-cost offshore farms may be profitable at the same prices or, especially, if they are able to command a premium price.

Summary of Insights from Supply and Demand Analysis

U.S. offshore fish farms may be economically viable even if other farms have lower costs, as long as the total supply from lower-cost farms is limited. What matters is not whether competitors can produce fish at a lower cost, but whether they can produce enough fish at a lower cost to keep prices below levels at which U.S. offshore farming is profitable.

For any given fish species, the economic viability of U.S. offshore fish farms depends on far more than the relative cost of U.S. offshore farming in comparison with other sources of world fish supply. Note that farming—rice, wheat, poultry, beef—occurs worldwide in countries and environments with vastly different costs of production, not just in the lowest-cost countries and environments.

Neither prices nor costs for U.S. offshore aquaculture or its potential competitors are fixed. Prices and costs may change over time, and as a result, the economic viability of different types of offshore aquaculture may change over time. The economic potential for U.S. offshore aquaculture will also respond to changes in either world demand or changes in world supply from any source.

Basic Economics of Aquaculture

We next discuss basic economics of aquaculture. We focus on factors important for considering the potential economic viability of a farm and the relative competitiveness of offshore farming. For purposes of this discussion, we simplify the analysis by expressing all costs and revenues on a per-pound basis. This requires converting all costs and revenues—including one-time investment costs—into costs and prices per pound. The appendix to this chapter explains how this may be done so that costs per pound are comparable to prices per pound.[5]

[5] As discussed in the appendix, a fish farm incurs costs and receives revenues over time. Prior to earning any revenues, a fish farm incurs initial one-time costs of planning, permitting, and capital investments for cages and other facilities. These are followed by further investments in juveniles and feed. After the first grow-out period, the

A Conceptual Framework

Figure 2.9 provides a conceptual framework for thinking about factors affecting the economic viability of a fish farm in a given location growing a particular species of fish. This is a useful conceptual framework to think about how the economic viability of farming in a particular type of location—offshore U.S. waters—compares with the economic viability of farming in other locations, such as inshore waters and foreign waters.

A fish farm is economically viable if the average price per pound received for the fish exceeds the average cost per pound of producing the fish. The cost per pound may be divided into four major cost components: facilities costs, feed costs, juvenile costs, and other operating costs. Each of these cost components is determined by cost parameters, which are driven in part by the farm design. A wide variety of external factors—shown on the left side of the diagram—drive both farm design and cost parameters. Some of the same and other external factors drive supply and demand conditions, which determine the price for which the farm can sell its fish.

Below, we first discuss major farm cost components and cost parameters. We then discuss how these are affected by different external factors, both directly and indirectly through farm design. We then discuss major factors affecting supply, demand and prices.

Facilities Cost

A marine fish farm requires a variety of capital investments. The most significant investments are typically for cages, boats, feeding and monitoring systems, onshore facilities (docks, storage facilities, and offices), and initial project planning (including design and permitting). For purposes of this discussion, we refer to the cost of these investments as a "facilities cost."

As discussed in the appendix to this chapter, any given total facilities cost of a fish farm may be converted into an equivalent annual facilities cost per year of production, which may be thought of as the annual equivalent payment that would be required to pay both principal and interest on a loan for the full cost of the investment over the lifetime of the investment.[6]

The facilities cost per pound is equal to:
(Equivalent annual facilities cost per year of production) / (Annual production in pounds)

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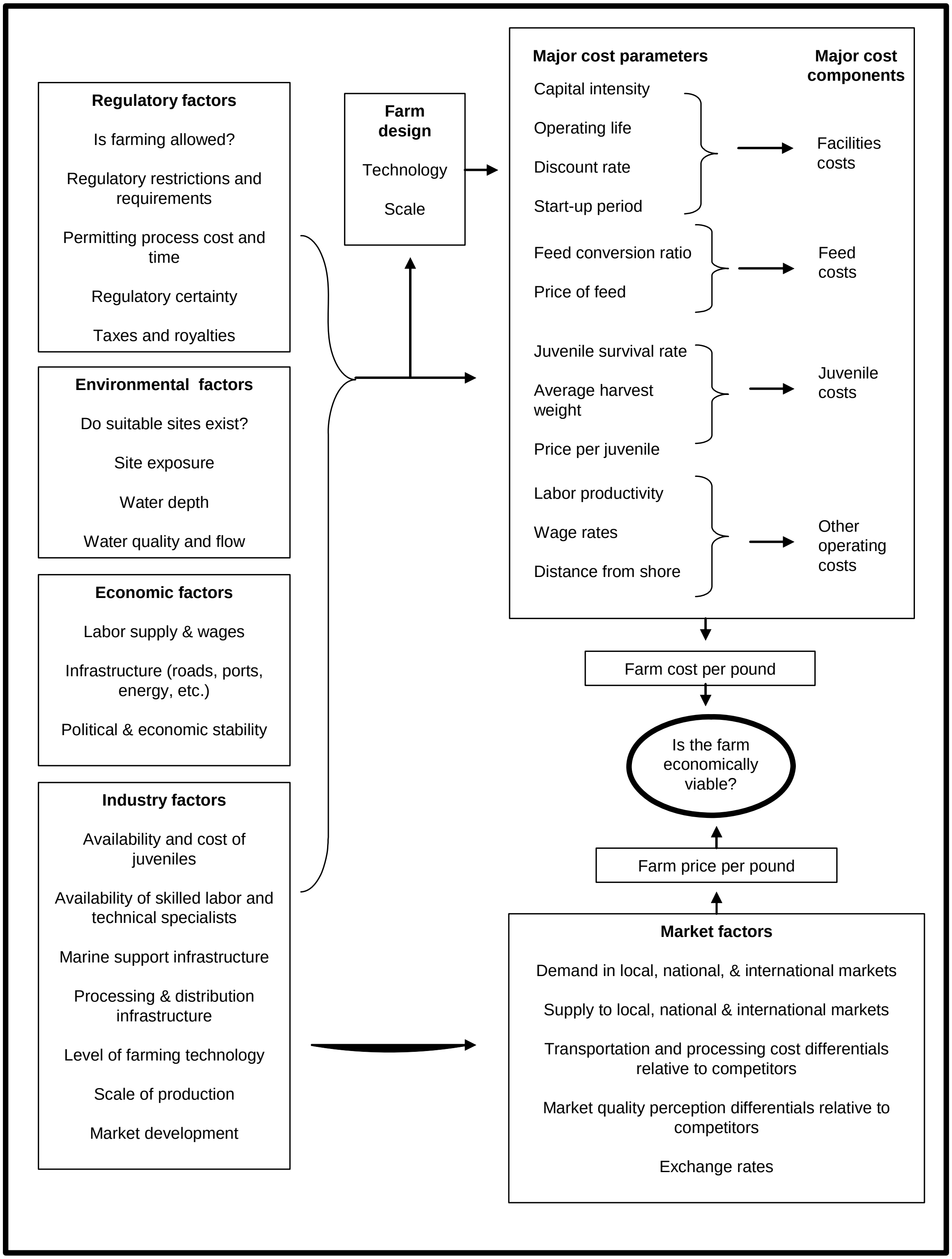
fish farm begins to earn revenues as the initial fish are harvested and sold. Over the operating life of the farm, the farm continues to incur additional costs of juveniles and feed as well annual operating and maintenance costs. Analysis of the profitability and economic viability of a fish farm requires comparison of the stream of costs incurred over time with the stream of revenues over time. This may be done using standard methods of investment analysis. In general, a farm is economically viable if the net discounted value of expected revenues over time exceeds the net discounted value of expected costs over time (including the risk-adjusted cost of capital). Thus, profitability depends not just on total costs and revenues, but also on the timing of costs and revenues over the life of the farm, and the risk-adjusted cost of capital.

[6] Financial analyses of fish farms often include "interest" and "depreciation." The concept of annual facilities cost as used here is approximately equal to the sum of interest and depreciation, with the assumption that interest and depreciation are identical for each year of facility life.

Figure 2.9. Major factors affecting the economic viability of a fish farm.



The most important factors affecting facilities cost per pound include:

- Capital intensity. For purposes of this analysis, we define "capital intensity" as the total initial investment per pound of annual production.
- Discount rate. This is the risk-adjusted opportunity cost of capital for the project. Depending on how the project is financed, this may be the interest rate which would be charged on a loan for the investment, or the rate of return which could be earned on an alternative investment of equivalent risk. For any given capital intensity, the higher the discount rate, the higher the facilities cost per pound.
- Operating life. This is the number of years with harvests to which facilities costs may be attributed. For any given capital intensity, the greater the number of years with harvests, the lower the facilities cost per pound.
- Start-up period. This is the period of time from when investments are made until harvests begin. For any given capital intensity, the longer the start-up period, the greater the facilities cost per pound.

Table 2.1 shows several examples of how the discount rate, operating life, and start-up period affect the facilities cost per pound for a fish farm with a hypothetical capital intensity of $1/lb. Note that for any given capital intensity of a fish farm, all three of these factors may significantly affect facilities costs per pound.

Feed Cost

Feed cost is one of the largest components of finfish farming costs. The most important factors affecting feed cost per pound of fish production include:

- Price of feed. This is the price per pound of feed purchased by the farm.
- Feed conversion ratio (FCR). This is the ratio of the total weight of feed eaten by a crop of fish (from the time they are purchased as juveniles to the time they are harvested) to the weight of the fish at harvest.

Feed cost per pound of fish is equal to:

(Price of feed) x (Feed conversion ratio).

Table 2.2 shows feed costs per pound for various hypothetical combinations of the price of feed and the feed conversion ratio.

Table 2.1. Effects of selected factors on facilities cost per pound for a hypothetical fish farm with a capital intensity of $1/lb.

Example	Discount rate	Operating life	Start-up period	Total years from investment until final harvest	Facilities cost per pound
A	**10%**	10	0	10	$0.16
B	**15%**	10	0	10	$0.20
C	**20%**	10	0	10	$0.24
D	10%	**10**	0	10	$0.16
E	10%	**20**	0	20	$0.12
F	10%	**100**	0	100	$0.10
G	10%	10	**0**	10	$0.16
H	10%	10	**2**	12	$0.20
I	10%	10	**5**	15	$0.26

Note: All examples assume a capital intensity of $1/lb (a one-time investment of one dollar per pound of annual production).

Table 2.2. Feed cost per pound of fish: Effects of price of feed and feed conversion ratio.

		Price of feed ($/lb)				
		$0.30	$0.40	$0.50	$0.60	$0.70
Feed conversion ratio = pounds of feed per pound of fish	1.00	$0.30	$0.40	$0.50	$0.60	$0.70
	1.25	$0.38	$0.50	$0.63	$0.75	$0.88
	1.50	$0.45	$0.60	$0.75	$0.90	$1.05
	1.75	$0.53	$0.70	$0.88	$1.05	$1.23
	2.00	$0.60	$0.80	$1.00	$1.20	$1.40
	2.25	$0.68	$0.90	$1.13	$1.35	$1.58

Note: Feed Cost per Pound of Fish Produced = (Price of Feed) x (Feed Conversion Ratio).

Feed costs per pound of fish vary depending upon the type of feed, species, feeding technology, and other factors affecting growth and survival rates of fish, including water quality. In general, two opposing trends are likely to affect future feed costs per pound for marine aquaculture. The price of feed may increase as rising feed demand puts upward pressure on prices of fish meal and fish oil, which are major inputs to feed production. Rising prices of feed will increase farmers' incentives to reduce feed costs by improving feed conversion ratios. This may be done in a number of ways, such as reducing fish mortality, developing better feeds that fish are able to utilize more efficiently, improving the timing and method of feeding, utilizing more vegetable-based feeds, and shifting production from carnivorous species to non-carnivorous species. Future aquaculture feed costs per pound will depend on the relative strength of these opposing trends.

Juvenile Cost

Juvenile cost is another important component of marine aquaculture cost. The most important factors affecting juvenile cost are:

- Price per juvenile. This is the delivered cost of individual juveniles purchased from a hatchery.
- Juvenile survival rate. This is the percentage of juveniles which survive to be harvested. It is equal to the inverse of the number of juveniles per harvested fish.
- Average harvest weight. This is the average weight of fish at harvest.

Juvenile cost per pound of fish harvested is equal to:

(Price per juvenile) * (Juveniles per harvested fish) / (Average harvest weight)
(Price per juvenile) / [(Juvenile survival rate) * (Average harvest weight)]

Table 2.3 shows juvenile costs per pound for various hypothetical combinations of price per juvenile, juvenile survival rate, and average harvest weight.

Relative Scale of Different Cost Components

Fish farming costs vary widely depending upon the species being farmed and where and how it is farmed. In general, however, feed and juveniles represent the largest cost components for most types of finfish farming, while operating costs and facilities costs tend to represent a much smaller share of total cost, even in offshore farms. This basic fact is important in considering the economics of offshore fish farming and its ability to compete with inshore farming, because while operating costs and facilities costs are likely to be higher offshore, feed and juvenile costs are likely to be the same—or potentially lower, if offshore water quality and water flow are better.

Table 2.3. Effects of Selected Factors on Fish Farm Juvenile Cost per Pound.

Juvenile survival rate	Avg. harvest weight (lbs)	Price per juvenile							
		$0.50	$0.75	$1.00	$1.25	$1.50	$2.00	$2.50	$3.00
100%	2	$0.25	$0.38	$0.50	$0.63	$0.75	$1.00	$1.25	$1.50
	4	$0.13	$0.19	$0.25	$0.31	$0.38	$0.50	$0.63	$0.75
	6	$0.08	$0.13	$0.17	$0.21	$0.25	$0.33	$0.42	$0.50
	8	$0.06	$0.09	$0.13	$0.16	$0.19	$0.25	$0.31	$0.38
	10	$0.05	$0.08	$0.10	$0.13	$0.15	$0.20	$0.25	$0.30
90%	2	$0.28	$0.42	$0.56	$0.69	$0.83	$1.11	$1.39	$1.67
	4	$0.14	$0.21	$0.28	$0.35	$0.42	$0.56	$0.69	$0.83
	6	$0.09	$0.14	$0.19	$0.23	$0.28	$0.37	$0.46	$0.56
	8	$0.07	$0.10	$0.14	$0.17	$0.21	$0.28	$0.35	$0.42
	10	$0.06	$0.08	$0.11	$0.14	$0.17	$0.22	$0.28	$0.33
80%	2	$0.31	$0.47	$0.63	$0.78	$0.94	$1.25	$1.56	$1.88
	4	$0.16	$0.23	$0.31	$0.39	$0.47	$0.63	$0.78	$0.94
	6	$0.10	$0.16	$0.21	$0.26	$0.31	$0.42	$0.52	$0.63
	8	$0.08	$0.12	$0.16	$0.20	$0.23	$0.31	$0.39	$0.47
	10	$0.06	$0.09	$0.13	$0.16	$0.19	$0.25	$0.31	$0.38

Note: Juvenile cost per pound = (Cost per juvenile) / [(Juvenile survival rate) * (Average harvest weight)]

The smaller the share of total costs represented by a particular cost element—such as facilities—the less significant the effect of an increase in that cost element will be in its relative effect on total cost. This basic mathematical principle is illustrated in Table 2.4. For example, suppose facilities costs and feed costs account for 10% and 50% of the total cost of an inshore farming operation, respectively. If facilities costs are 100% higher for an offshore farm, they would result in only a 10% increase in total cost. Such an increase in facilities costs would be fully offset by a 20% decrease in feed costs.

Table 2.4. Percentage increase in total cost resulting from an increase in one cost component.

		Percentage of cost component in total cost				
		10%	20%	30%	40%	50%
Percentage increase in cost component	10%	1%	2%	3%	4%	5%
	20%	2%	4%	6%	8%	10%
	50%	5%	10%	15%	20%	25%
	100%	10%	20%	30%	40%	50%
	200%	20%	40%	60%	80%	100%
	300%	30%	60%	90%	120%	150%

Farm Design

Some cost parameters are influenced by the farm design: the technology used by the farm and the scale of the farm (Figure 2.9). These cost parameters include capital intensity, operating life, feed conversion ratio, juvenile survival rate, and labor productivity. In general, as in other kinds of agriculture, fish farmers face a choice between capital intensity and other cost parameters. By increasing the capital intensity of the farm (which increases facility costs) farmers can achieve better feed conversion ratios, better juvenile survival rates, and higher labor productivity (which lowers feed costs, juvenile costs, and other operating costs).

An important point to recognize is that cost-minimizing design choices for offshore farming may differ from those for inshore farming, and cost-minimizing design choices for U.S. offshore farms may differ from those for foreign offshore farms. For example, if labor costs more per hour for an offshore farm than for an inshore farm, an offshore farm is likely to use relatively less labor—thus reducing the extent to which higher labor costs represent a cost disadvantage.

Regulatory Factors

Regulatory factors directly affect the economic viability of fish farming—most obviously by prescribing whether farming is allowed at all, but also in numerous other ways. Regulatory restrictions and requirements may limit farm design choices of scale and technology and may impose additional costs, such as environmental monitoring. The permitting process may represent a significant expense which increases with the time required for permitting and the uncertainty associated with the outcome. Regulatory certainty—the likelihood that regulations will stay the same over the life of the farm—affects the risk associated with farming investments and the discount rate for facilities investments. Taxes and royalties represent additional direct costs.

Put simply, to a significant extent the costs and economic viability of fish farming depends on how it is regulated. Favorable regulation cannot make a fish farm economically viable if environmental, economic, industry, and market factors are unfavorable. But unfavorable regulation can keep a farm from being economically viable even if other factors are favorable.

Environmental Factors

Key environmental factors affecting economic viability of a fish farm include site exposure, water depth, and water flow. Exposure to waves and wind directly determines what kinds of cages and other farm equipment will work, as well as the risks of farm damage and loss of fish. Water depth affects installation costs. Water depth, quality, and flow affect feed costs and juvenile costs by affecting fish growth rates and mortality rates. Water depth, quality, and flow also affect potential environmental effects of a farm and the extent to which these must be mitigated, either because it is in the farmer's own interest or in response to regulatory requirements.

Economic Factors

General economic conditions affect the costs and economic viability of a fish farm. Key economic factors include labor supply and wages, transportation infrastructure, and availability and cost of utilities. Another critical factor is political and economic stability, including protection of property and basic rule of law.

Industry Factors

The costs and economic viability of an individual fish farm are affected by a number of industry factors which depend on the scale and experience of the industry. As the scale of the fish farming industry within a region or nation grows, it creates a demand for specialized aquaculture support activities, such as hatcheries, veterinary services, fish transport, and processing. As the scale of these activities expands, it tends to lower costs and expand the types and scale of farming which are feasible. More generally, experience gained in farming drives technological change. Industry factors may be thought of as "feedback factors" affecting economic viability, in the sense that as an industry grows and gains experience, economies of scale and technological change help to lower costs and further expand the industry.

Market Factors

Price is as important as cost to the economic viability of a fish farm. The price per pound received by a farm is driven by a wide variety of market factors interacting in complex ways. The effects of these factors can generally be described within the supply and demand framework presented earlier in this chapter.

Which market factors are most important depends on the size of the market and the relative scale of competition. If a fish farm is supplying a market or markets which are also supplied with comparable fish of comparable quality from competing sources, the volume of competing supply and the prices offered by competitors are key factors influencing the price received by the farm. Put differently, the price depends on whether the demand for the fish is local, national, or international, and whether the competing supply is local, national, or international.

Different factors also drive prices in the short term (over the course of one or a few years) than over the long term (the expected period of operation of a fish farm). In the short term, prices are driven by the total supply available to the market, given current production. Over the longer term, prices are driven by the capacity of producers to expand or contract production in response to higher or lower prices.

In national and international markets, competition typically occurs at the wholesale level, between fish which have undergone primary processing and been transported either to end-market locations or locations where further processing occurs. The price paid to a fish farm is driven not only by the wholesale price, but also by the costs of processing and transportation, which must be subtracted from the wholesale price. Put differently, whether a fish farm can be competitive is determined not just by the cost of growing the fish, but also by the costs of processing the fish and transporting it to markets. In considering whether a particular farming operation can be competitive, an important factor is how both processing costs and transportation costs to markets compare with those of competitors. A higher-cost farm can be competitive if its products can be processed at a lower cost or shipped to markets at a lower cost than its competitors.

Both processing and transportation costs depend in part on the scale of the industry. A pioneer fish farm in one location may face relatively high processing and transportation costs if the fish processing industry and transportation infrastructure are not well developed. As the industry grows in scale, these costs may decline significantly, making fish farms relatively more competitive. Thus, some of the industry scale factors which affect the costs of a fish farm also affect the prices paid to a fish farm, through their effects on the costs of processing and transportation.

A similarly important factor is the perceived quality of a farm's products compared with competing suppliers' products, as reflected in the relative prices that buyers are willing to pay. A higher-cost farm can be competitive if its products can command a higher price over those of competitors.

Competitiveness of U. S. Offshore Aquaculture

The economic viability of a fish farm depends on its costs and the prices it receives for its products. Prices depend in part on the prices received by competitors in the same markets, which in turn depend in part on competitors' costs. Thus the economic viability of a fish farm depends, in part, on the competitiveness of the farm: how its prices and costs compare with those of competitors supplying the same markets.

Table 2.5 suggests a simple typology of potential competitors for U.S. offshore aquaculture. By "competitor," we mean a fish producer who might supply similar fish to similar markets as U.S. offshore fish farmers. The table below suggests which producers are most likely to be competitors of U.S. offshore fish farming during "early" development of offshore farming, and which are most likely to be competitors if or when offshore farming achieves large-scale commodity production. Note that wild fisheries are not considered a likely, significant competitor of future large-scale offshore aquaculture production, because those fisheries are unlikely to be able to expand production.

Table 2.5. A typology of potential competitors for U.S. offshore aquaculture.

	United States	Other Developed Countries	Undeveloped countries
Offshore farming		F	F
Inshore farming	e, f	E, F	E, F
Onshore farming	e		E, F
Wild fisheries	e		

E = major early competitor; e = minor early competitor
F = major future competitor; f = minor future competitor
Arrows indicate focus of discussion in text.

Following is a discussion of the competitiveness of offshore farming relative to inshore farming, as indicated by the vertical arrows in the table. This is followed by a discussion of the competitiveness of domestic offshore farming, relative to offshore farming abroad. The goal is to highlight key considerations in thinking about the competitiveness of U.S. offshore farming—in particular, reasons why costs and prices may be higher or lower for U.S. offshore farming than for its competitors.

The goal is *not* to discuss the competitiveness of U.S. offshore farming with respect to every potential competitor. For example, no attempt is made to discuss how competitive U.S. offshore farming might be with inshore or onshore farming in other countries.

Competitive Disadvantages of Offshore Farming Relative to Inshore Farming

Exposure

Probably the greatest competitive disadvantages of offshore aquaculture derive from the technical challenges and costs of constructing, installing, operating, and maintaining cages and feeding and monitoring systems able to withstand wave and wind conditions in an exposed ocean environment. A more exposed environment also adds to the required sizes and construction and operating costs of support vessels. This cost disadvantage may be significantly reduced where there are synergies with existing or new offshore facilities built for other purposes, such as offshore oil platforms or (as envisioned for the future) wave power generation installations.

Support transport costs

Offshore farms are (by definition) located farther from shore than onshore farms. In general, this will mean that fish, feed, and workers will need to be transported over greater distances, adding to fuel and labor costs. Note, however, that locating a farm farther offshore does not necessarily imply a greater transportation distance when compared to available inshore sites. Depending on terrain, infrastructure development, and the extent of the existing inshore farming industry, offshore facilities will not necessarily be farther from onshore support facilities such as docks and roads than are available protected inshore sites. Put simply, it may be shorter and quicker for a support vessel to travel three miles straight out to sea than five miles up the coast or around a cape to the next bay.

Water depth

In general, water depth is greater for offshore farms, and may in some cases be much greater—adding to the costs of mooring systems.

Working conditions

Offshore farms will likely need to pay higher wage rates for workers able and willing to work in a harsher and riskier offshore environment and able to work with the more complex technology of offshore farms. Note, however, that higher wage rates may be significantly offset by the use of more capital-intensive and labor-saving technology, such as remote feeding and monitoring systems.

Industry economies of scale

The costs of manufacturing cages and offshore feeding and monitoring systems depend upon the scale at which they are produced. Currently, far fewer cages and feeding and monitoring systems are being built for offshore farming than for inshore farming. Over time, as the scale of offshore investment expands, it will help to lower manufacturing costs for offshore cages and feeding and monitoring systems.

Operating experience

For almost any economic activity, operating experience helps to identify better and cheaper ways of doing things. Worldwide, there has been far less experience in building and maintaining offshore farms than inshore farms. Over time, as more experience is gained with offshore farming, costs are likely to decline at a relatively greater rate.

Regulatory experience

Experience with the regulation of offshore farming lags behind the regulation of inshore aquaculture. Regulatory frameworks and effective methods for offshore farm monitoring and regulatory enforcement may not be in place. Potential jurisdictional and legal issues may not have been resolved. This lack of experience is likely to increase the difficulty, time, costs, and risks associated with applying for offshore sites and meeting regulatory requirements. Over time, as more regulatory experience is gained, these offshore costs are likely to decline until they compare with those of inshore farming.

Competitive Advantages of Offshore Farming Relative to Inshore Farming

Water quality

Water quality is critical to successful fish farming. In general, offshore farms will have more water flow than inshore farms. Offshore farms are also less likely to be affected by pollution from land-based sources, such as agricultural runoff. Better water quality contributes to better growing conditions for fish and is reflected in better feed conversion and survival rates, lowering the costs of feed, juveniles, and facilities and other costs (on a per-pound basis).

Availability of sites

For much of the world's coastlines, "inshore" farming is not an option because there are no protected waters in which to locate such farms. In areas with protected waters, inshore farming may still not be possible because available sites are already being used. In addition, the best inshore sites tend to be used first, so new inshore sites will be even less economically competitive, relatively speaking, with offshore sites. In contrast, available sites for offshore farming are almost limitless in comparison to the potential scale of offshore farming for the foreseeable future.

Conflicts with other activities

Because of their greater distance from shore, offshore farms are likely to experience fewer conflicts with other economic and recreational uses of the environment. This reduced potential for conflicts may result in fewer restrictions on farm size and greater economies of scale, as discussed below.

Environmental impacts

Because of greater water flow and depth, the potential for fish feces, fish feed, or other farm residues to concentrate in the water or on the ocean bottom is comparatively less. The potential for interaction with species migrating close to shore or with concentrations of migrating anadromous fish is also less. Such reduced environmental impacts may result in fewer restrictions on farm size and greater economies of scale.

Farm economies of scale

Because of the greater availability of suitable large-scale farming sites and the potential for fewer regulatory restrictions on farm size, offshore farms have the potential to be larger, allowing for reduced costs through greater economies of scale.

Distance from markets

Because of reduced conflicts with other activities and greater availability of sites, it may be possible to locate offshore farms closer to markets (such as major cities), thus reducing transportation costs and making it possible for fresher products to be delivered to markets. This may, in turn, allow some offshore farms to capture higher prices than more distant, inshore farms.

Other Considerations for the Competitiveness of Offshore Farming with Inshore Farming

An uncertain factor affecting the relative economic viability of offshore aquaculture is its relative *political viability:* the choices of society—through the political process and legal, political, and regulatory institutions at local, state, and national levels—about whether to allow offshore aquaculture and how to regulate it. The relative political viability of offshore aquaculture may depend on the relative geographical distribution of perceived costs and benefits.

Suppose inshore aquaculture is regulated by multiple local (state-level or lower) authorities, while offshore aquaculture is regulated by a single, national authority. A simple political theory would suggest that regulation of inshore aquaculture would reflect perceptions at local levels of the relative costs and benefits of inshore aquaculture, while regulation of offshore aquaculture would reflect national perceptions of these costs and benefits. The relative geographical distribution of perceived costs and benefits of inshore and offshore aquaculture is likely to differ for different regions and different types of farming. This may result in more economically favorable local regulation of inshore aquaculture in some areas, and less economically favorable regulation of inshore aquaculture in other areas—relative to national standards for offshore regulation.

Competitiveness of Offshore Farming with Inshore Farming: Summary

As summarized in Table 2.6, a large number of factors may affect the relative competitiveness of offshore farming with inshore farming in different ways, through their effects on costs, on price, and more. There is no obvious or single answer about whether offshore farming could be competitive with inshore farming. The answer depends upon the specific circumstances of location and species farmed. In general, facility and operating costs are likely to be higher for offshore farming. However, these cost disadvantages may be offset by improved water quality, greater availability of sites, fewer conflicts with other activities, and reduced environmental impacts. As offshore aquaculture grows in scale and experience, it will tend to become relatively more competitive.

Wherever it develops, large-scale offshore fish farming will be an inherently capital- and technology-intensive activity. It will generally tend to look the same. As a result and as discussed below, the differences between the United States and other countries which might affect the competitiveness of U.S. offshore farming are likely to be less dramatic than the differences between offshore and inshore farming.

Environmental conditions

The United States EEZ is a very large area extending from the Arctic to the tropics, with a wide range of temperature, depth, wave, wind, and ice conditions. In general, the United States has favorable water temperatures for a wide variety of offshore aquaculture. However, in much of this area, other environmental factors—such as wave exposure—are less favorable compared to some potential foreign competitors. U.S. offshore aquaculture is most likely to be successful where favorable water temperature and wave exposure conditions for the offshore farming of a species combine with favorable economic conditions—particularly infrastructure and distance to markets.

Table 2.6. Selected factors which may affect the relative competitiveness of offshore farming with inshore farming (N = negative factors; P = positive factors).

	Type of effect					
	Facility costs	**Feed costs**	**Juvenile costs**	**Other costs**	**Price**	**Other effects**
Exposure	N			N		
Support transport costs				N		
Water depth	N					
Working conditions				N		
Industry economies of scale	N*					
Operating experience	N*			N*		
Regulatory experience						N*
Water quality	P	P	P	P		
Availability of sites						P
Conflicts with other activies						P
Environmental impacts						P
Farm economies of scale	P			P		
Distance from markets					P	
Political viability						?

*Factors likely to decline in significance over time as the scale of offshore aquaculture increases and more experience is gained.

Competitiveness of United States Offshore Farming with Foreign Offshore Farming

Feed prices

Feed costs represent the single, most important cost component for many kinds of fish farming. Aquaculture feeds and feed components (fish meal, fish oil, and vegetable-based feed inputs such as soybeans) are globally traded products for which prices follow similar trends worldwide. Thus, in general, feed prices are unlikely to represent either a major competitive disadvantage or advantage for U.S. offshore farms.

However, feed prices may differ to the extent that they are impacted by transportation costs. U.S. agricultural products, such as soybeans, are becoming an increasingly important ingredient in world fish feed production. Lower costs of transporting these agricultural feeds could become a competitive advantage for U.S. offshore farming, as is the case for domestic livestock production.

Note also that feed costs depend not only on feed prices but also on the efficiency of feed utilization. To the extent that U.S. offshore farms are able to achieve better feed conversion ratios through better water quality and superior technology, they may enjoy a competitive advantage in feed costs.

Juvenile costs

Juveniles represent another major cost of fish farming. The production of juveniles may be considered a specialized type of onshore fish farming. Major cost factors for juvenile production include facilities costs, labor costs, level of technology, and scale of production. Clearly, the United States is able to produce juveniles for commercial fish farming at a price and on a scale which is globally competitive. For example, Washington-based Troutlodge, Inc. is a world-renowned trout and salmon breeding company, exporting trout eggs to 26 foreign countries.[7] The United States produces very large quantities of juveniles for recreational fisheries and salmon hatcheries, including the extensive Alaska salmon hatchery system which supports major Alaska commercial pink and chum salmon fisheries. In the short-term, however, local hatchery capacity may be limited or non-existent for some of the species which are potential candidates for U.S. offshore farming. This may represent an important competitive disadvantage until U.S. marine fish farming—including offshore farming—reaches a larger scale.

Distance to U.S. markets

One of the most important competitive advantages of U.S. offshore farming may be the shorter distance to U.S. markets. This is particularly important for fresh fish which would have to be shipped by air to reach U.S. markets. It is relatively less important for the large-scale production of frozen fish. In the future, "food miles" could become an important factor for some markets where consumers or buyers are concerned about greenhouse gas releases associated with food production and transportation. If so, this would tend to favor domestic producers of fish in supplying the U.S. market. Note that this transportation cost advantage would not apply equally to all U.S. offshore aquaculture production. Alaska, in particular, is located a significant distance from U.S. markets.

Labor costs

Although typically less than feed and juvenile costs, labor also represents a significant cost factor in fish farming. In general, annual costs per worker (wage rates and benefits) in the United States are similar to those in other developed countries that are potential competitors (such as Canada and Norway). But U.S. costs are higher than those of less economically developed, potential competitors (such as Chile and Vietnam). Given the geography of world economic development, labor cost differentials are more likely to be a significant competitive factor for warm-water offshore farming than for cold-water offshore farming. Wherever it occurs, offshore farming is likely to be highly mechanized and will utilize relatively fewer, but more skilled, workers than inshore farming. As a result, the fact that some potential competitors have lower labor costs may not be a particularly significant factor for the competitiveness of U.S. offshore fish farming.

Put differently, higher labor costs do not mean that the United States could not compete in offshore fish farming. Norway and Chile currently dominate world production of farmed salmon. Although Norway has higher labor costs, it is able to compete successfully with Chile in many (but not all) markets due to other advantages, such as lower transportation costs.

Differences in labor costs may represent an important consideration for the competitiveness of U.S. offshore fish farming not so much in farming but in the subsequent processing of fish. Some types of fish processing, such as extracting pin-bones from salmon, are

[7]Source: www.troutlodge.com.

highly labor intensive. Increasingly, U.S. fish (Alaska salmon and pollock, for example) are being frozen and exported to low-labor cost countries such as China for value-added processing into products such as portioned fillets for re-export to markets in the United States and Europe. For species or products requiring labor-intensive processing, U.S. labor costs or the costs of shipping fish to other countries for processing could offset the potential transportation-cost advantage of growing fish closer to U.S. markets.

Facilities costs

In well-developed aquaculture industries, such as salmon farming, cage design tends to be similar worldwide. However, cages are usually built locally, and cage costs may differ according to labor costs and local availability of materials. Other offshore farming facilities and equipment—including nets, monitoring and feeding systems, and the large boats which would be used to support them—are sourced globally and are likely to cost about the same, regardless of where farming occurs.

Industry scale

The U. S. marine aquaculture industry is currently much smaller than that of major marine fish farming countries such as Norway and Chile. This represents a potential competitive disadvantage with respect to the availability and cost of specialized support infrastructure (such as hatcheries) and technical support services (such as veterinary services). These disadvantages would decline over time as a domestic marine farming industry grows in scale. One of the most important components of support infrastructure—the fish processing industry—is well developed in many areas of the United States where large-scale wild fisheries are found. Marine aquaculture production could improve the utilization of existing processing facilities, thus lowering those costs for wild fisheries.

Economic infrastructure

With the significant exception of many parts of Alaska, the United States has a highly developed physical and service infrastructure—roads, airports, utilities, construction services, vessel repair and maintenance services, electronics installation and repair services, for example. This represents a competitive advantage for the United States in offshore farming over less developed countries, and would help to offset the labor cost advantages these countries may enjoy.

Political and economic stability

For major investments such as offshore fish farms, political and economic stability—in particular the security of property rights and the rule of law—is essential. With regard to some less developed countries, the fact that the United States is a stable and safe place to do business may be a significant competitive advantage.

Economic Modeling of U.S. Offshore Aquaculture

As suggested by the preceding discussion, there is no single answer about the economic viability of U.S. offshore fish farming. The economic viability of offshore fish farms may vary widely depending upon where they are located, the species that are farmed, how they are regulated, how they are designed, and the scale of operation. Economic viability may also change over time as the scale of the industry changes and as markets change.

To move beyond these general conclusions to a more formal assessment of the prospects for a particular type of farm—or for U. S. offshore aquaculture in general—requires the development of models that explicitly consider both expected costs and prices. Such models may range from simple "back of the envelope" models based on rules-of-thumb for different types of costs, to complex systems of equations based on numerous, carefully researched assumptions.

Table 2.7 provides an example of a relatively simple economic model of a hypothetical offshore fish farm for a hypothetical fish species. It is not intended to represent actual costs or prices for any particular fish species, or the economic viability of any particular kind of fish farming. It simply presents one potential approach to economic modeling of a fish farm. There are many other potential approaches. Which approach is best depends on the purpose for which the model is being developed and the reliability of the assumptions on which that model is based. In general, more complex models may be used to address more complex questions but require more assumptions and may be harder to understand. (Chapter 6 of this study provides an example of a more complex economic model of an offshore fish farm.)

The model is driven by 21 assumptions: 9 technical assumptions (rows 1-9) and 12 price and cost assumptions (rows 10-21). All of the model outputs (rows 22-53) are driven by these 21 assumptions. The fifth column of the table ("Explanation or formula") explains how outputs are calculated from the assumptions. The sixth column illustrates the model calculations, based on hypothetical technical, price, and cost assumptions.

The model incorporates three common economic viability indicators: net present value, internal rate of return, and annual economic profit (rows 44-46). These all depend upon operating profit, total investment, the cost of capital, the facility life, and the start-up period. The "net present value" indicator shows whether the net present value of the farm's annual operating profits over the facilities life exceeds the cost of the investment. The "internal rate of return" indicator shows whether the farm's annual operating revenues are providing a rate of return which exceeds the annual cost of capital. The "annual economic profit" indicator shows the farm's annual profits after subtracting the "annual economic cost of capital" (row 42), defined as what equal annual payments would be on a loan for the total investment cost paid off over the period of time for which harvests occur.

Economic models such as the one in Table 2.7 are important tools for analyzing the economic viability of offshore fish farming. Perhaps the first benefit of economic models is that they require the user to think systematically about costs and prices. This can be difficult, particularly for farms which do not yet exist and for which those costs and prices cannot actually be observed. However, ultimately there is no substitute for careful thinking about what the costs and prices may be, utilizing the best available information—particularly when contemplating actual investments.

Table 2.7. Economic model of a hypothetical offshore fish farm.

	Row	Variable name	Units	Explanation or formula	Value
Technical assumptions	1	Annual production volume	pounds	Total annual production of farm operation	10,000,000
	2	**Production per cubic meter***	pounds	Net pen production per cubic meter	**40**
	3	Individual pen volume	$meters^3$	Volume of an individual net pen	10,000
	4	Average weight	pounds	Average weight of fish at harvest	7
	5	**Juvenile survival rate***	%	% of juvenile fish which survive to harvest	**80%**
	6	**Feed conversion ratio***	ratio	Pounds of feed per pounds harvested	**1.2**
	7	Productivity	pounds	pounds per person per year	600,000
	8	Facility life	years	Years from investment to final harvest	15
	9	Startup period	years	Startup years without harvests	1
Price & cost assumptions	10	**Fish price***	$	Price received per pound, FOB processor	**$1.30**
	11	**Net pen cost per cubic meter***	$	Fully-installed cost per cubic meter of net pen	**$30**
	12	Other offshore investment per pen	$	Costs of feeders and other equipment per pen	$50,000
	13	Other investment	$	Support vessels and onshore facilities	$1,500,000
	14	**Cost per juvenile***	$	Cost per juvenile fish, including interest	**$1.65**
	15	**Feed cost per pound***	$	Cost of feed per pound	**$0.33**
	16	Average staff cost	$	Average annual staff pay and benefits	$50,000
	17	Fish insurance rate	%	Percentage of annual production value	4%
	18	Facilities insurance rate	%	Percentage of value of investment	2%
	19	Other annual costs	$	Annual costs of fuel, diving, utilities, monitoring, & administration	$880,000
	20	Annual repair and maintenance rate	%	Annual cost of repairs and maintenance expressed as a percentage of total fixed capital investment	7%
	21	**Annual cost of capital rate***	%	Annual cost of capital expressed as a % of total fixed capital investment	**15%**
Technical outputs	22	Total pen volume	$meters^3$	(Annual production) /(production per cubic meter)	250,000
	23	Number of net pens	number	(Total net pen volume) / (Individual net pen volume)	25
	24	Annual fish	number	(Annual production) / (Average weight)	1,428,571
	25	Number of juveniles	number	(Annual # of fish produced) / (Juvenile survival rate)	1,785,714
	26	Volume of feed	pounds	(Annual production) x (Feed conversion ratio)	12,000,000
	27	Number of staff	number	(Annual production) / (Productivity)	16.7
Investment outputs	28	Net pen investment	$	(Total pen volume) x (Net pen cost per cubic meter)	$7,500,000
	29	Other offshore investment	$	(Other offshore investment per pen) x (Number of net pens)	$1,250,000
	30	Total investment	$	(Net pen investment) + (Other offshore investment) + (Other investment)	$10,250,000

Table 2.7 (continued). Economic model of a hypothetical offshore fish farm.

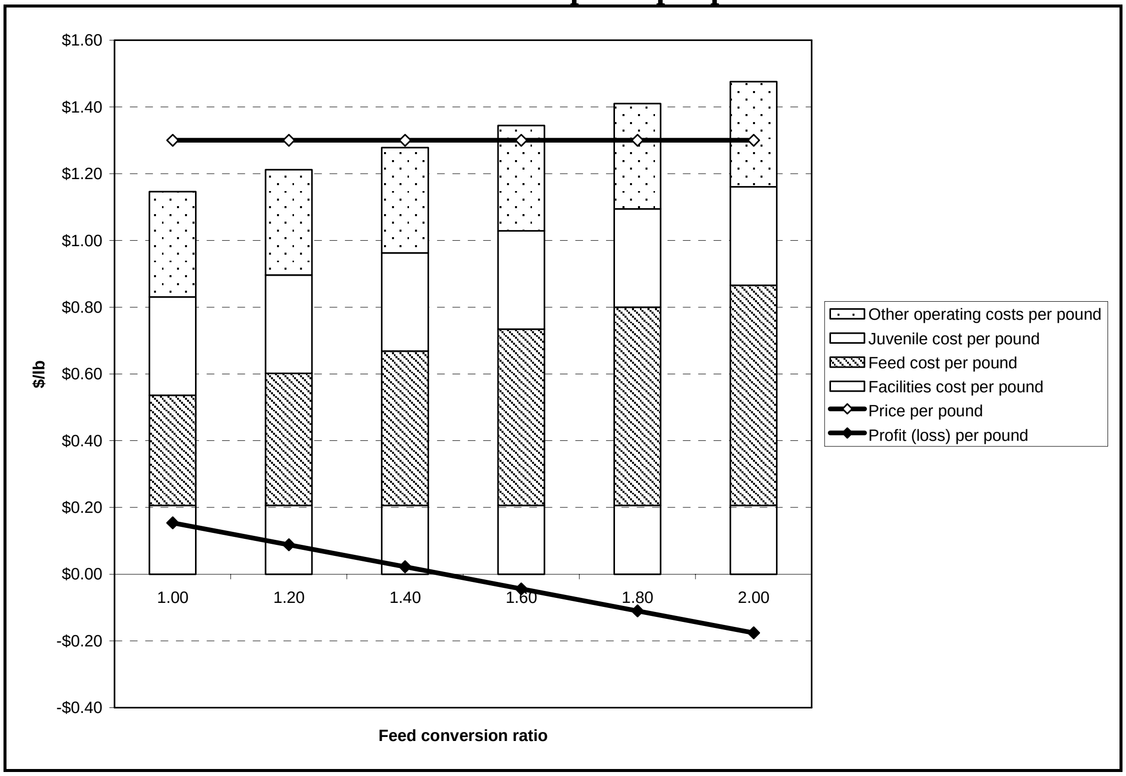
	Row	Variable name	Units	Explanation or formula	Value
Operating cost outputs	31	Cost of juveniles	$	(Number of juveniles purchased) x (Cost per juvenile)	$2,946,429
	32	Cost of feed	$	(Volume of feed) x (Feed price per pound)	$3,960,000
	33	Payroll cost	$	(Number of staff) x (average staff cost)	$833,333
	34	Fish insurance cost	$	(Fish insurance rate) x (Annual sales value)	$520,000
	35	Facilities insurance cost		(Facilities insurance rate) x (Total fixed capital investment)	$205,000
	36	Repair & maintenance cost	$	(Annual repair & maintenance rate) x (Total fixed capital investment)	$717,500
	37	Other costs	$	(Assumed)	$880,000
	38	Annual operating cost	$	Total of operating costs listed above	$10,062,262
Summary financial outputs	39	Annual sales	$	(Annual volume) x (Fish price)	$13,000,000
	40	- Annual operating cost	$	Calculated above	$10,062,262
	41	**(=) Annual operating profit (or loss)**	**$**		**$2,937,738**
	42	- Annual economic cost of capital	$	See discussion in text	$2,059,141
	43	**(=) Annual economic profit (or loss)**	**$**		**$878,598**
Economic feasibility indicators	44	Annual economic profit (or loss)	$	(Annual operating cost) - (annual cost of capital)	$878,598
	45	Net Present Value	$	See discussion in text.	$4,373,487
	46	Internal Rate of Return	%	See discussion in text.	22%
Costs, price and profits per pound	47	Feed cost per pound	$/lb	(Cost of feed) / (Annual production volume)	$0.40
	48	Juveniles cost per pound	$/lb	(Cost of juveniles) / (Annual production volume)	$0.29
	49	Other operating costs per pound	$/lb	(Sum of rows 33-37) / (Annual production volume)	$0.32
	50	Facilities cost per pound	$/lb	(Row 42) / (Annual production volume)	$0.21
	51	Total cost per pound	$/lb	(Sum of rows 47-50)	$1.21
	52	Price per pound	$/lb	Fish price	$1.30
	53	Profit (loss) per pound	$/lb	(Price per pound) - (total cost per pound)	$0.09

Note: Critical factors affecting economic viability are shown in **bold**.

Sensitivity analysis

A second benefit of an economic model is that it provides a mechanism for testing the implications of changes in model assumptions. In thinking about economic viability, what is important is not just the best estimate of economic viability, but how this estimate might be affected by changing key model assumptions. For example, Figure 2.10 illustrates how different assumptions about the feed conversion ratio for our hypothetical fish farm affect feed cost per pound and profit per pound. At feed conversion ratios of less that 1.47 the farm is profitable; at higher feed conversion ratios the farm is not profitable.

Figure 2.10. Effect of feed conversion ratio on profit per pound.

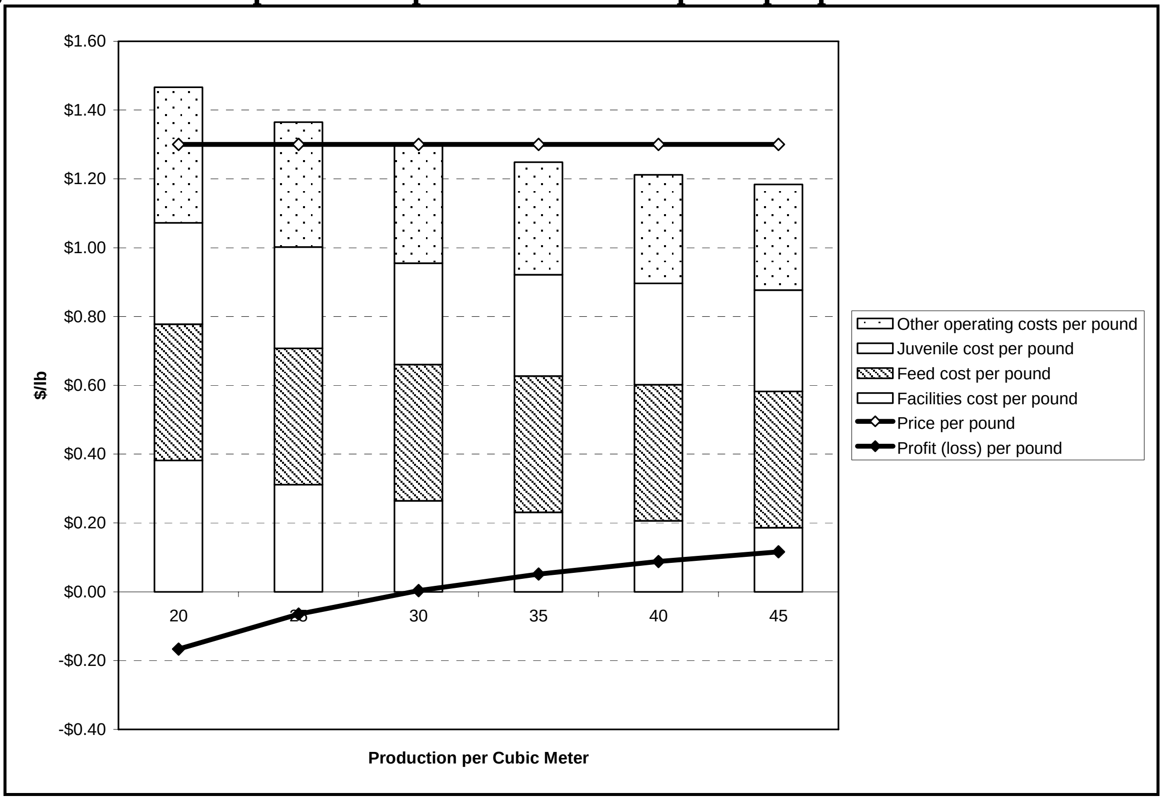


As another example, Figure 2.11 illustrates how different assumptions about production per cubic meter affect facilities cost per pound and profit per pound. If annual production per cubic meter is 30 pounds or higher, the farm is profitable; if production is lower, the farm is not profitable.

Optimization analysis

Investors face numerous choices in the design of a fish farm. For example, the scale of a farm may affect costs in many ways, ranging from initial investment costs to labor costs. A third benefit of an economic model is that it can be used to refine the design of a farm to explore trade-offs between different design choices and to minimize costs or maximize profits. Similarly, economic models may be used to examine the implications of how farms are regulated—such as imposing size limits.

Figure 2.11. Effect of production per cubic meter on profit per pound.



Economic impact analysis

Economic models of particular farming operations can provide the starting assumptions for analysis of economic impacts, both direct and indirect—such as the jobs and income that might be created by offshore farming. (Chapter 7 of this study provides an example of a model of potential economic impacts of offshore fish farming.)

This brief discussion of modeling has addressed only the modeling of the economic viability of an individual fish farm. To formally analyze the economic potential for the U.S. offshore farming industry would be a much more complex task. Doing so would require developing not one, but a set of economic models of different kinds of farms for varying fish species in different types of locations. It would also require systematic analysis of U.S. and global fish markets to examine how U.S. and global prices may change in the future for those species which might be produced by domestic offshore farms—and how those markets might be affected, over time, by the development of U.S. offshore farming.

The Limits of Economic Analysis for Assessing Economic Potential

The true test of the economic potential of an industry is not an economic study or model. It is the market. Successful new industries do not develop because of government-sponsored "intelligent design." Successful new industries develop because many new ideas are tried—and some of those ideas prove profitable. Government can best stimulate development of new industries by allowing and encouraging new ideas to be tried.

At present, offshore aquaculture in this country is in the same situation as farming would be if all land were publicly owned and there was no clear process for obtaining a right to farm public lands. The federal government controls federal waters. No matter how interested investors may be in taking risks to develop offshore aquaculture, they cannot do so without federal authorization. U.S. offshore aquaculture cannot develop without an enabling regulatory structure.

This does not, of course, mean that an enabling regulatory structure would necessarily lead to a profitable or large-scale domestic offshore aquaculture industry. But the fact that some investors are interested in offshore aquaculture in the United States suggests that certain types of offshore fish farming may be feasible at some scale. The only way to know if they are feasible is to allow them to be tried.

The success of some offshore fish farms, over time, will help make offshore fish farming more viable, as experience is gained, technology develops, and the scale of the industry grows. Thus, offshore aquaculture could become a profitable and valuable new industry for the United States.

Conclusions

A wide spectrum of offshore aquaculture could potentially be undertaken within the vast area of the U.S. Exclusive Economic Zone. Many different species could potentially be farmed, in many different places, using many different kinds of technologies, for many different markets. There is no single answer about the economic potential for these many types of endeavors. The answers vary for different species, locations, and technologies.

The world offshore aquaculture industry remains in its infancy. There has been only limited experience on which to judge its future potential. It is impossible to know with certainty what the long-run economic opportunities for U.S. offshore aquaculture may be.

Offshore aquaculture will face competition from other sources of fish supply, including inshore aquaculture, foreign offshore aquaculture, and wild fisheries. To be economically viable, domestic offshore aquaculture does not necessarily have to match competitors' costs of production. Even if U.S. offshore farming costs are higher, the industry can be viable if lower-cost competitors are highly profitable; if U.S. offshore farming can command a price premium over lower-cost competitors; or if lower-cost competitors are unable to meet the demands of specific market niches.

In meeting growing domestic and world demand for fish, U.S. offshore aquaculture has both potential competitive disadvantages and advantages relative to other aquaculture producers. Table 2.8 summarizes some of the potentially most significant of these.

Table 2.8. Potential competitive disadvantages and advantages of U.S. offshore aquaculture.

	Potential competitive disadvantages	Potential competitive advantages
Relative to inshore farms	Technological challenges in constructing cages and feeding and monitoring systems able to withstand exposed ocean environment Higher costs of capital facilities Higher costs of transportation	Greater availability of potential farming sites Higher water quality Fewer conflicts with other economic and recreational activities
Relative to foreign farms	Higher labor costs Small scale of existing U.S. marine aquaculture industry and support industries	Lower costs of transportation to local markets and to the U.S. market High level of technological development Well-developed transportation infrastructure Highly skilled work force Stable political and economic system

In competing with wild fisheries, in general, it will be difficult for U.S. offshore aquaculture to compete with those for which supply is year-round, reliable, and abundant. However, where wild fisheries are unable to meet market demand for a species at particular times, in particular locations, or for particular product characteristics, competitive opportunities will be created for aquaculture, including offshore aquaculture.

At its current scale and given current technology, offshore aquaculture is a relatively high-cost way of growing fish. Currently, in the United States and elsewhere, offshore aquaculture is probably able to compete with inshore aquaculture only under limited circumstances, such as:

- When offshore farms are able to supply market niches which cannot be supplied by inshore farms, for reasons such as a lack of suitable sites, regulatory constraints, and transportation costs.
- When offshore weather and wave conditions are relatively mild, reducing the costs of building and operating offshore facilities relative to inshore aquaculture.
- When offshore farms enjoy significantly better water conditions than inshore farms, enabling faster growth or better survival.
- When offshore farms are able to take advantage of cost-lowering synergies with other facilities or activities, such as existing inshore farm facilities or offshore oil rigs.

Over time, however, the economic potential for offshore aquaculture—including U.S. offshore aquaculture—is likely to grow, for several reasons:

- Growing population and income will increase world demand for fish, raising prices and increasing the utilization of limited onshore and near-shore areas suitable for aquaculture. These same factors will also increase the relative value of competing uses of potential onshore and inshore farming areas.

- Technological change is likely to lower the cost of offshore aquaculture relative to inshore aquaculture. As in all industries (including onshore and inshore aquaculture) there will be a learning curve for U.S. offshore aquaculture. Over time, experience will help to identify ways to reduce costs (as well as operational designs and practices to minimize environmental impacts).

- As offshore aquaculture grows, economies of scale will help to bring costs down.

Among the most important factors affecting the economic potential for U.S. offshore aquaculture will be:

- The extent and pace of technological development in areas such as remote monitoring, remote feeding, and cage construction, and the extent to which these technological developments can reduce costs and risks of offshore farming.
- The extent to which offshore farms are able to achieve better growth rates and survival than inshore farms.
- The extent to which offshore facilities face fewer conflicts with other activities than inshore farms.
- The extent to which offshore farming is able to develop to a level at which it begins to realize significant economies of scale, and to spur development of key supporting industries such as hatcheries, veterinary services, cage manufacture, and processing.
- The extent to which an enabling regulatory framework establishes clear, stable, and timely processes for permitting and regulating offshore farms.

The economic potential for U.S. offshore aquaculture depends critically on how it is regulated. Part of the answer to the question, "What kind of offshore aquaculture could we have?" depends on the answer to the question, "What kind of offshore aquaculture do we want?"

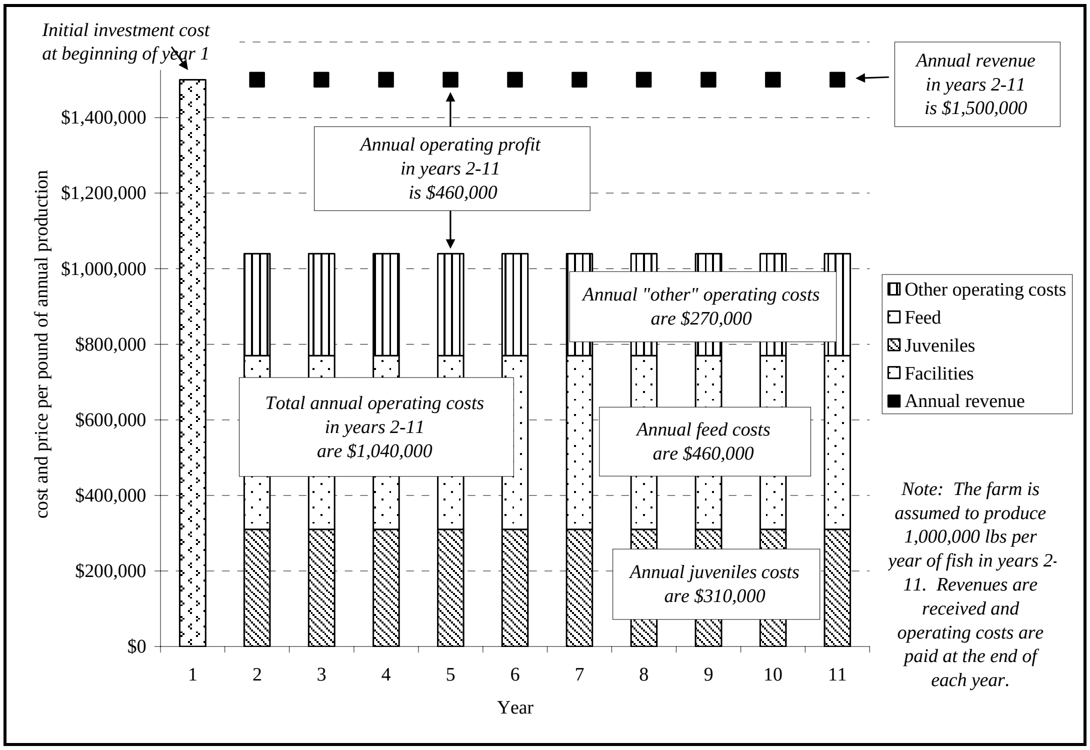
The true test of the economic potential of any industry is the market. No offshore aquaculture industry can develop in the United States without an enabling regulatory structure. Only by letting offshore aquaculture be tried can we learn what its economic potential might be.

Appendix: Converting Fish Farm Costs and Revenues to Costs and Prices per Pound

This appendix presents a simple approach to assessing the economic viability of a fish farm by converting costs and revenues over time to costs per pound and price per pound.

A fish farm experiences a series of costs and revenues over time. As illustrated for a hypothetical fish farm in Figure 2.A1, costs include both initial investments in facilities (cages, boats, and other capital equipment) as well as annual costs for juveniles, feed, and other operating costs (labor, utilities, insurance, administration, etc.). Revenues begin only after a start-up period in which initial investments are made.

Figure 2.A1. Costs, revenues and operating profits for a hypothetical fish farm.



Formally assessing the economic viability of a fish farm requires comparing these costs and revenues at different points in time. Using standard investment analysis, a fish farm is economically viable if the net present value of the stream of costs and revenues over time is positive, or if:

$$NPV = \sum(R_t - C_t)^{-(1+r)t} \geq 0$$

As shown in Table 2.A2, the net present value and economic viability of our hypothetical fish farm depends on the discount rate. The higher the discount rate, the lower the net present value. At a discount rate of 17.8%, the net present value falls to zero and the farm is barely economically viable. At higher discount rates, the farm is not economically viable.

Table 2.A2. Net present value of a hypothetical fish farm.

	Payment	Years	Net Present Value				
Discount rate			10.0%	13.0%	16.0%	17.8%	19.0%
Investment costs	-$1,500,000	1	-$1,500,000	-$1,500,000	-$1,500,000	-$1,500,000	-$1,500,000
Operating costs	-$1,040,000	2-11	-$5,281,281	-$4,419,526	-$3,735,550	-$3,391,304	-$3,186,563
Revenues	$1,500,000	2-11	$7,617,232	$6,374,317	$5,387,813	$4,891,305	$4,596,005
Total			$835,951	$454,791	$152,263	$0	-$90,559
Is the farm economically viable?			*Yes*	*Yes*	*Yes*	*Barely*	*No*

Calculating and comparing the net present value of different kinds of aquaculture projects, as illustrated in Table 2.A2, is complicated. We may simplify the analysis and comparison by expressing all costs and revenues on an average, per-pound basis. This involves the following steps:

- Calculate average price per pound received for the fish
- Calculate average annual operating costs per pound, expressed as of the time of sale of the fish. Thus, the costs of juveniles and feed would include interest costs for the period of time between when costs are incurred and when fish are sold.
- Express facilities cost per pound on an "equivalent annual cost" basis. This translates investment costs in facilities such as net-pens into equivalent costs per year of production.[8]

If we express all revenues and costs on an average per-pound basis, then the fish farm is economically viable if the price per pound exceeds the total cost per pound (including the equivalent annual cost per pound of facilities investments). Mathematically, if all revenues and costs are converted to an average per-pound basis as described above, the total cost per pound will be less than the price per pound only if the net present value of revenues minus costs is greater than zero.

Table 2.A3 illustrates these calculations for our hypothetical fish farm. Note that as the discount rate increases, the facilities cost per pound increases and the profit per pound declines. At a discount rate of 17.8%, the profit per pound falls to zero and the farm is barely economically viable. At higher discount rates, profit per pound is negative and the farm is not viable.

Table 2.A3. Price, cost and profit per pound for a hypothetical fish farm.

Cost per pound	*Discount rate*	*10.0%*	*13.0%*	*16.0%*	*17.8%*	*19.0%*
	Facilities costs per pound*	$0.30	$0.35	$0.42	$0.46	$0.49
	Feed costs per pound	$0.31	$0.31	$0.31	$0.31	$0.31
	Juvenile cost per pound	$0.46	$0.46	$0.46	$0.46	$0.46
	Other operating costs per pound	$0.27	$0.27	$0.27	$0.27	$0.27
	Total cost per pound	**$1.34**	**$1.39**	**$1.46**	**$1.50**	**$1.53**
Price per pound		**$1.50**	**$1.50**	**$1.50**	**$1.50**	**$1.50**
Profit or loss per pound		**$0.16**	**$0.11**	**$0.04**	**$0.00**	**-$0.03**
Is the farm economically viable?		*Yes*	*Yes*	*Yes*	*Barely*	*No*

*Facilities costs per pound are expressed on an equivalent annual cost basis.

[8] Equivalent annual cost is "the cost per year of owning and operating an asset over its entire lifespan. EAC is calculated by dividing the NPV of a project by the present value of an annuity factor. Equivalently, the NPV of the project may be multiplied by the loan repayment factor." (http://en.wikipedia.org/wiki/Equivalent_Annual_Cost). Put simply, equivalent annual cost may be thought of as the annual payment on the loans needed to fully finance facilities investments in equal, annual installments over the years in which harvests occur. Like payments on house mortgages or car loans, the annual payments include both interest and principal. For the analysis in this chapter, we calculated equivalent annual costs using the PMT function in Excel.